Journal of Himalayan Earth Sciences Volume 53, No. 2, 2020 pp. 70-77

AVO analysis of Post-Stack Seismic data of Cretaceous Lumshiwal Formation in Kabirwala Block, Central Indus Basin Pakistan

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Abstract

The current study intends to use the amplitude versus offset (AVO) analysis technique for future hydrocarbon exploration by using post-stack seismic and well data (Panjpir 01) of Kabirwala Block, Pakistan. This analysis encompasses the estimation of AVO intercept and gradient from the amplitude of first arrivals (P-wave) to the sine squared of the angle of incidence in Lumshiwal Formation. Fluid replacement model is also used to calculate the shear component by replacement of fluids (oil, gas, and water) by using Gassmann equations. The offset synthetic seismogram is constructed by using P-wave sonic, density and S-wave logs response for the analysis of intercept and gradient of reflections in both gas and water cases. Interpretation of Gradient-Intercept analysis revealed that Lumshiwal Formation's sands lying in 4th quadrant of gradient-intercept cross-pots which depicts there is a gas anomaly, such sands also having 20% effective porosity.

Keywords: Amplitude-versus-offset (AVO), Lumshiwal Formation; Shear wave log (S-wave log), Fluid Replacement Model (FRM), Gradient-Intercept cross-plot, 4th quadrant

1. Introduction

Amplitude versus offset (AVO) has brought a great advancement in the seismic data interpretation for the last two decades. AVO intercept and S-wave data are normally used in conjunction with pre-stack waveform inversion in a hybrid inversion scheme. AVO interpretation is mainly depending on the cross-plotting of intercept (A), gradient (B), and pseudo Poisson's ratio to specify different lithological units and reservoir fluids (Bakhtiaril, et al., 2014). Such cross plotting of AVO common attributes can be further used to determine AVO classes (Castagna and Swan, 1997; Foster and Keys, 1999) and hydrocarbon-bearing sediments (Ross and Kinmann, 1995; Verm and Hilterman, 1995).

The study area (Kabirwala Block) is a part of Punjab Platform and located near to Khanewal District of the Punjab region (Fig. 1). The Punjab Platform which lies in the eastern segment of the Central Indus Basin is tectonically stable because of the greater distance from collision zone of Indian and Eurasian plate. It is a broad monocline that gently dipping towards the Suleiman Depression (Kadri, 1995). Punjab Platform is bounded by Sargodha High (to north), Mari-Kandhkot High (to south), Bikaner-Nagaur Basin (to east) and Suleiman Depression (in the west) (Sohail and Aadil, 2014).

In the recent past years, the Punjab Platform was targeted with more than twenty onshore exploratory wells for the hydrocarbon exploration (Aadil and Sohail, 2011). In the study area, the Cretaceous Chichali Formation acts as the main source rock while the Jurassic Samana Suk Formation and Lumshiwal Formation are considered as reservoir rocks within the Punjab Platform. Normal faults and unconformity provide the traps for the hydrocarbon migration. Similarly, the Samana Suk and Lumshiwal Formations are the proven gas-producing reservoirs in the Panjpir and Nandpur gas fields.

In this study, AVO modeling is performed on the selected seismic data for the reservoir characterization. The major purpose of the current study is to study the reservoir quality, to understand the seismic response when different fluids are present within the reservoir, AVO modeling was performed on the given data with the reference of hydrocarbon exploration, and these models can be used to predict the reservoir fluid (oil, gas, or water).

A total of fourteen (14) time migrated seismic lines with well data of Panjpir-01 (Fig. 1) are used for the AVO modeling. A synthetic seismogram is generated from the logs data of Panjpir-01 (Fig. 2) for the verification of the different horizons on the reference seismic section of line number 854-KBR-74 (Fig. 3).

2. Amplitude versus offset Modeling

AVO (amplitude variation with offset) modeling plays an important role in seismic data interpretation. It enhances reservoir characterization and reduces the risk in hydrocarbon exploration. AVO modelling has conducted using following procedure (Fig. 4).

2.1 Shear Component (S-Wave Log) and Poisson Ratio

S-wave log is mandatory in making of an offset dependent synthetic seismogram created by using Castagna's mud rock equation. S-wave log is also further used for the calculation of Poisson's ratio log (Fig. 5).

Poisson's ratio computes the distortion of material occurring normal to the stress. It has the ability to measure rock's strength which is another important rock property related to compressional stress. It characterizes the lateral deformation of the material and most of materials have a Poisson's ratio value ranging between 0.0 and 0.5. This elastic constant is named for Simeon Poisson, a French mathematician. Poisson's ratio (σ) can be expressed in terms of properties that can be measured in the field, including P wave's velocities and S-waves (equation 1).

$$\sigma = \tfrac{1}{2}(V_P^2 - 2V_S^2)/(V_P^2 - V_S^2) \quad (1)$$

Where σ =Possion's ration, Vp and Vs are compressional and shear wave velocities

Poisson's ratio for carbonate rocks is ~0.3, for sandstones ~0.2, and greater than 0.3 for shale. Poisson's ratio is dimensionless property having ranges lying between 0.1 and 0.45. Poisson's ratio ranges between 0.1–0.25, depicts that the rocks are vulnerable to fracture whereas Poisson's ratio ranges from 0.35 to 0.45, indicates that more strees is needed to have a fractured rock. Poisson's ratio varies from layer to layer and can be computed with the help of sonic log at depth of interest. The sonic log gives the travel time of shear and compressional wavelength which are further utilized for the calculation of the Poisson's ratio. (Belyadi, et al., 2019).

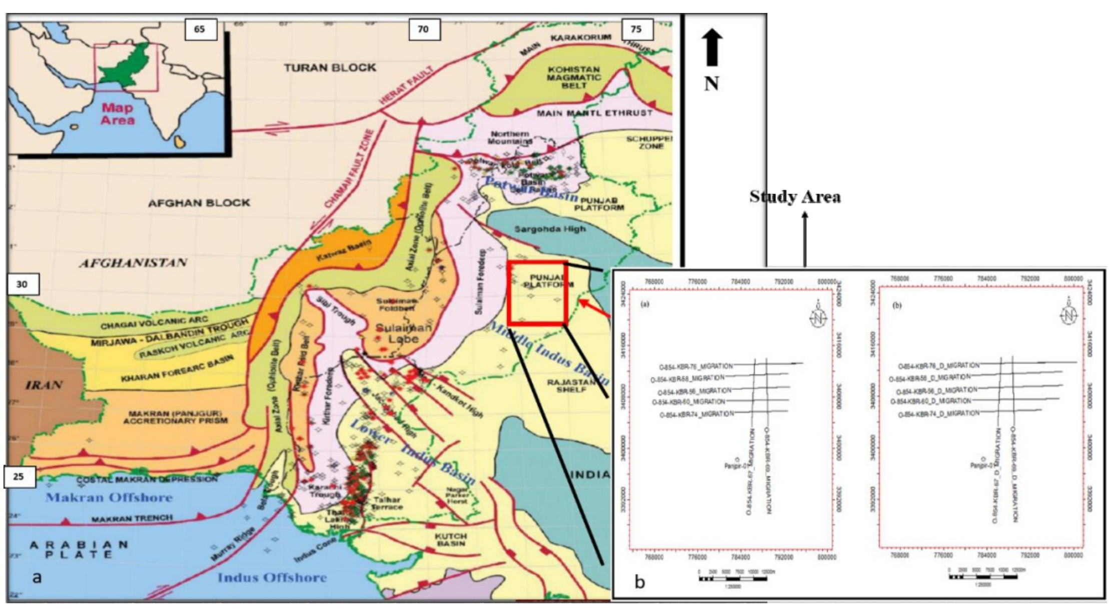

Fig. 1. (a) Generalize Tectonic map of Pakistan (Kadri, 1995). Study area enclosed in square (red color). (b) Base map of study area showing orientations of seismic lines.

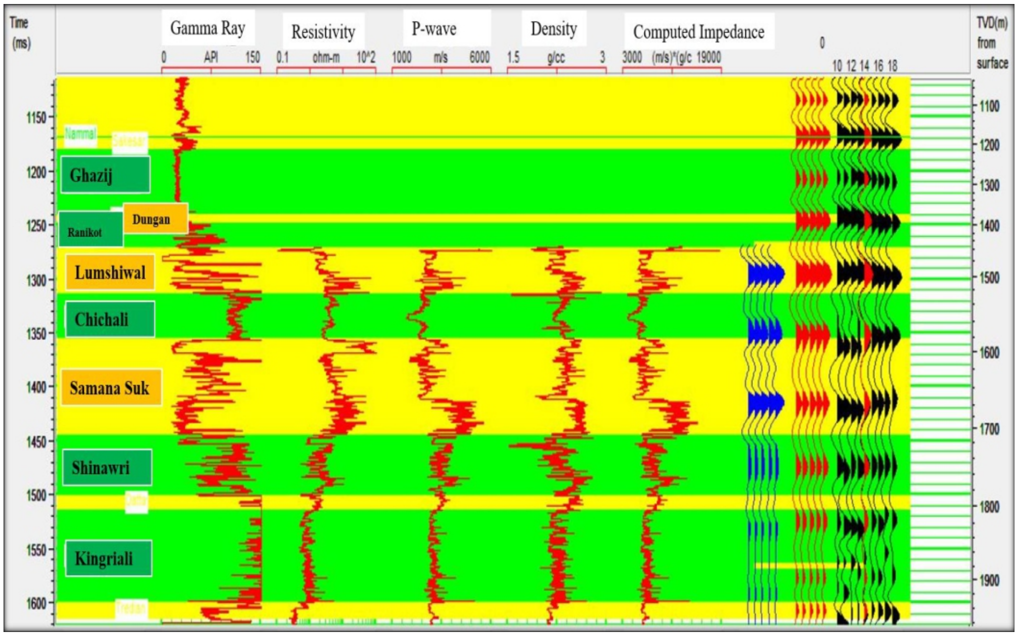

Fig. 2. Synthetic seismogram of well Panjpir-01, for the purpose of well to seismic tie to verify Formation tops on seismic profile at well location. At right side it provide depth while at left side it shows two way time (TWT) of Formations top.

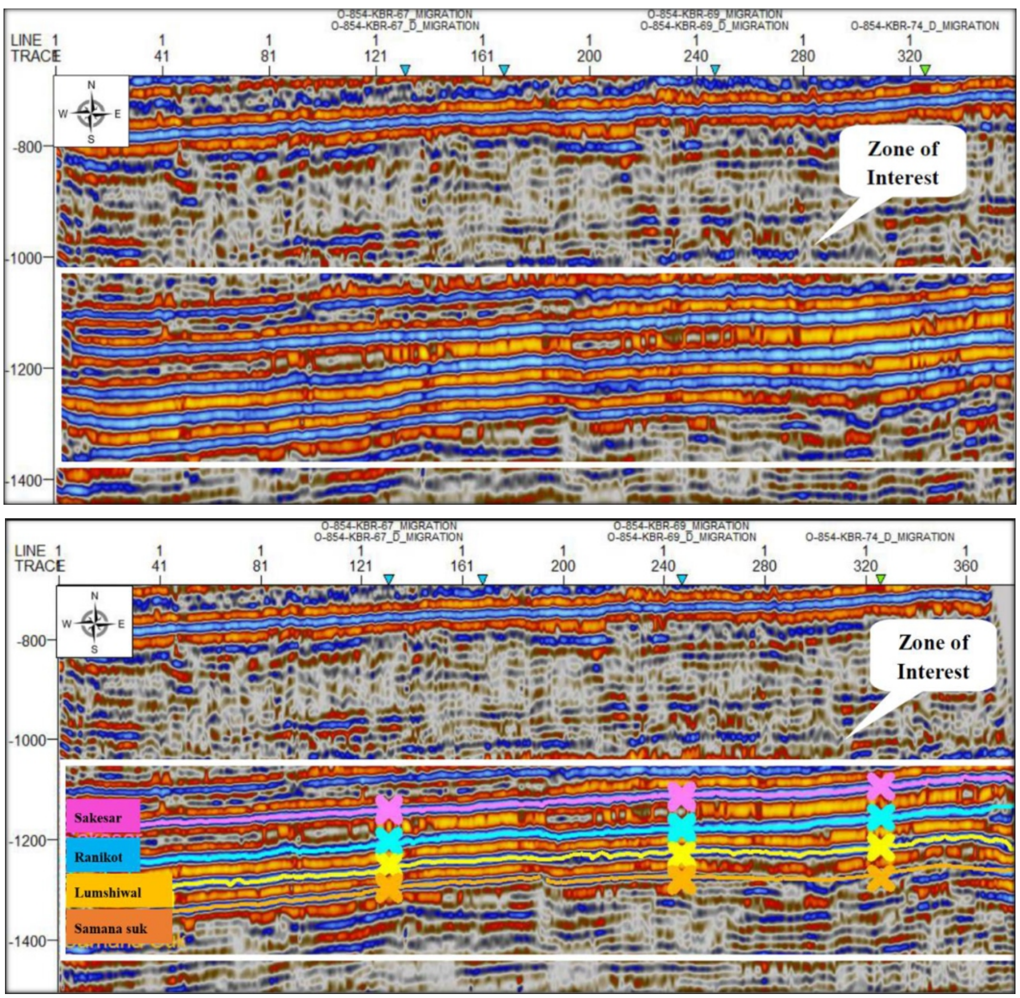

Fig. 3. Uninterpreted and Interpreted Reference Seismic Section (854-KBR-74) with marked seismic horizons in the order Sakesar, Ranikot, Lumshiwal and Samana Suk.

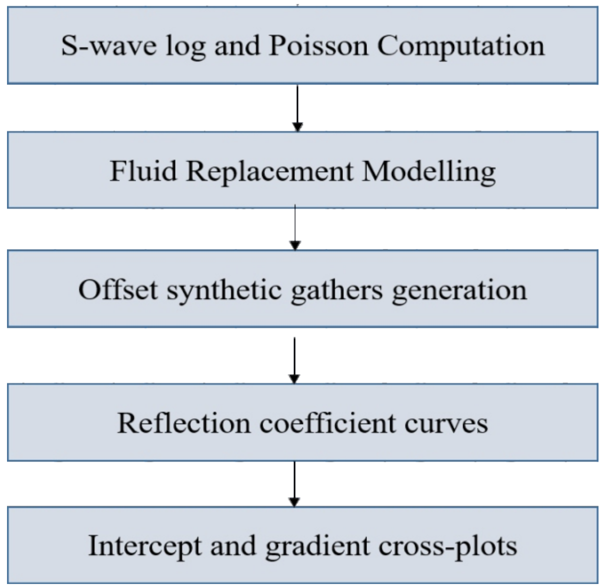

Fig. 4. Schematic diagram showing the steps followed for AVO modelling.

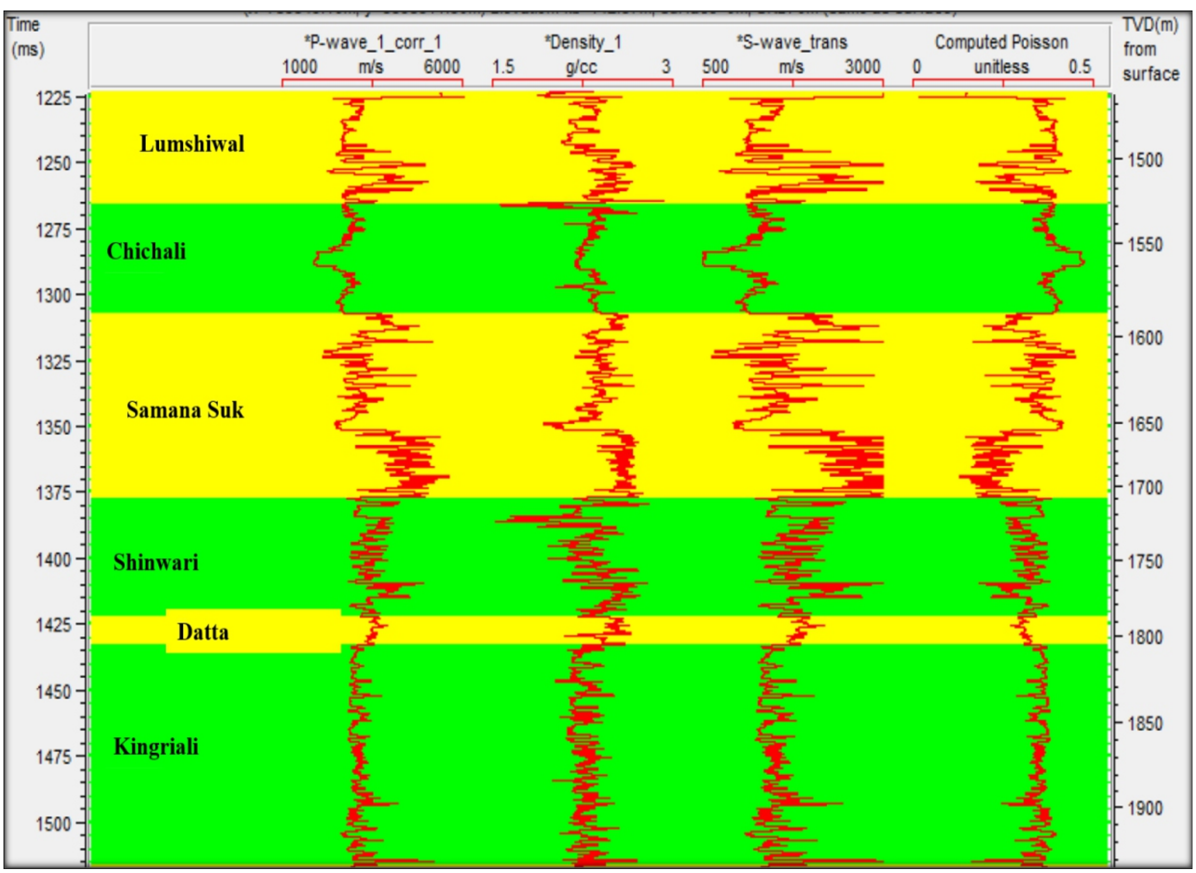

Fig. 5. Shear component and Poisson ratio computed of different Formations using P-wave and density log data.

2.2 *Fluid Replacement Modeling (FRM)*

The FRM has performed on Lumshiwal Formation to model the seismic velocity and density at brine and gas saturation levels (Fig. 6) The input data (Vp, Vs, density, neutron porosity, Vp/Vs and GR) for the application of the Gassmann fluid substitution were obtained for Panpir-01 well. Two saturation models (brine and gas) were calculated for pure sandstone and were used to measure the sensitivity of the saturation at different intervals.

By changing the fluid saturation (oil, gas or water) in the reservoir to generates seismic responses which is based on changing the elastic rock properties resulting from various reservoir rock conditions by using Gassmann equation.

Whereas,

$$K_s = K_d + \Delta K_d \qquad (2a)$$

$$\Delta K_d = \frac{K_o\left(1-\frac{K_d}{K_o}\right)}{1-\phi-\frac{K_d}{K_o}+\phi\frac{K_o}{K_f}}\phi \qquad (2b)$$

$$\mu_s = \mu_d \qquad (3)$$

K_0, K_f, K_d, and K_s, are the bulk moduli of the mineral, fluid, dry rock, and saturated rock frame, respectively.

Φ is porosity

μs and μd are the saturated and dry rock shear moduli.

ΔKd is an increment of bulk modulus caused by fluid saturation.

2.3 Offset-Dependent Synthetic Seismogram

Offset-dependent synthetic seismogram is generated by using sonic (P-wave), density and S-wave logs. Statistical Wavelet Extraction method (SWE) is used to extract the wavelet from seismic data and created offset-synthetic seismogram for the gas and water case (Fig. 7). It is interesting to notice that brine sand shows somehow same response as gas sand whereas a little difference in reflection coefficient (RC) values with the increasing of incident angle. Figure 7a and 7b actually gives amplitudes data and these little differences in amplitudes response can't be visualized. RC values vary more in brine sand than gas sand with the increase of incident angle (Fig. 7c).

In addition, with respect to different incidence angles, amplitude behavior is observed in the reservoir interval for the both gas and water in the studied well. On the basis of these observations, with the increase of an incident angle, there is a decrease in the reflection coefficient or amplitude in the reservoir zone (Fig. 7c). As indicated from (Fig. 8) at 0^o incidence angle there is -0.0.362 reflection coefficient value i.e. negative intercept and increases with the increase of incidence angles. While an increase in the reflection coefficient value depicts decrease in the amplitudes or in a direction from strong negative value to less negative (Positive gradient). After putting the intercept and gradient values in the Rutherford and William's (1989) intercept-gradient cross-plot, a class 4 anomaly for Lumshiwal Formation is resulted. This decrease in amplitudes of the reflection provides information about anomalies which are further discussed in AVO curves and Intercept-gradient cross-plots.

2.4 Reflection Coefficient Curves

Rutherford and Williams (1989) classified reflection coefficient curves and become widely used in the exploration industry. They classified AVO into three main types based on the acoustic impedance contrast. These classes further associated with bright spot, phase reversal and dim out developed for the interpretation of reflections from hydrocarbon saturated formations.

The current research determined that the reflection coefficients of the reflections in both cases i.e. (water and gas) initially become more negative but later on with offset it becomes less negative (Fig. 7c). In the result, according to the standard classification of Castagna and Sawan (1997), the Cretaceous Lumshiwal Formation has Class 4 anomaly.

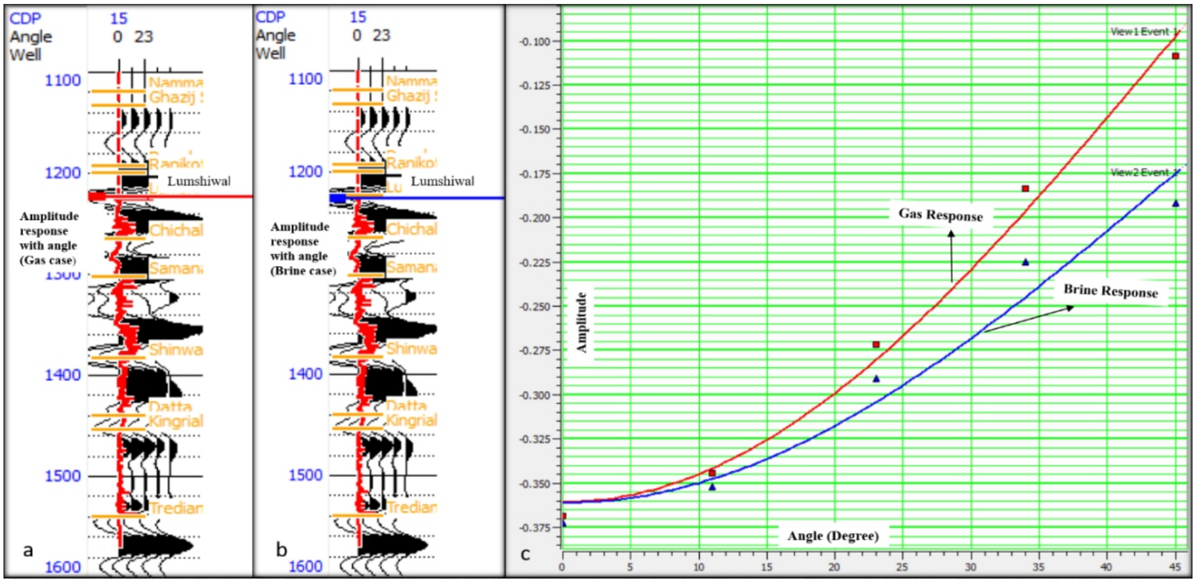

Fig. 6. Fluid Replacement Model (FRM) to evaluate the reservoir (Lumshiwal sands) response (amplitudes at different incident angles) at different saturated conditions (gas and brine).

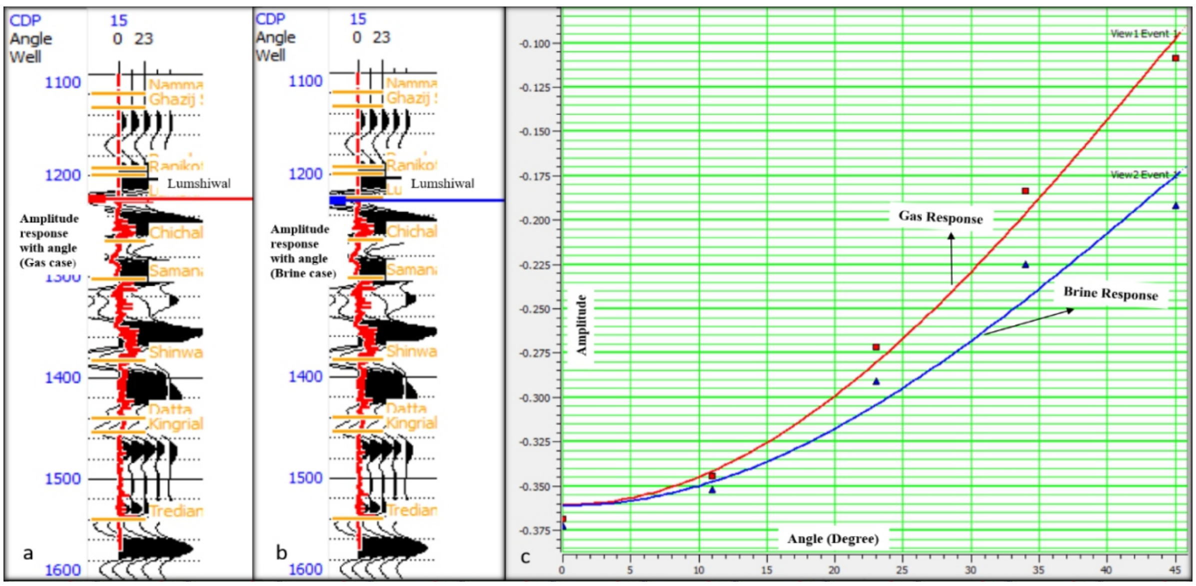

Fig. 7. Offset synthetic seismogram (a) showing response of Lumshiwal Formations at gas saturation (b) Lumshiwal Formation response at brine saturation (c) reflection coefficients response at brine (blue) and gas (red) case at different incident angles.

2.5 Intercept and Gradient

The intercept-gradient-cross-plot is extensively used for the amplitude variation with offset analysis in hydrocarbon exploration. Intercept is the zero offset reflection amplitude while gradient is the change in reflection amplitude with offset or incidence angle (Castagna and Swan, 1997). Rutherford and Williams (2016) demonstrated the ideal intercept-gradient cross-plot response for clastic rocks to analyze the changes in porosity and pore fluid (Fig. 8a)

This study interpreted the amplitudes of reflections initially recognized negative but moving towards the positive or less negative direction with an increase in incident angles so the intercept of the amplitudes found negative, but the gradient is positive with the different offset. After putting the values of intercept and gradients (class 4 anomaly) clearly indicated that it is laying in 4th quadrant and composed of gas (Fig. 8b and 8c).

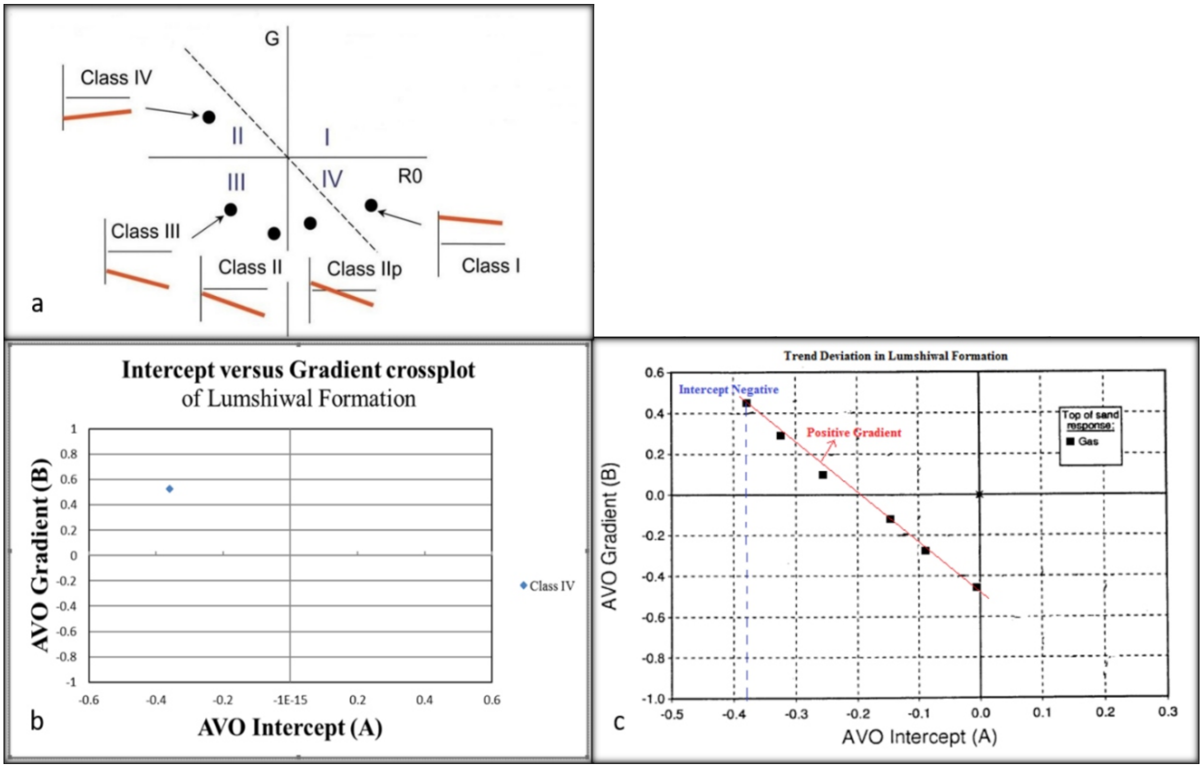

Fig. 8. (a) AVO cross plotting base on Rutherford and Williams (1989) AVO classes (b) Intercept versus gradient cross plot of the target zone in gas case shows the type IV sand anomaly. (c) Trend deviation analysis in Lumshiwal Formation.

3. AVO Interpretations

The amplitude versus offset (AVO) analysis on well and seismic data can provide valuable exploration and development information. In good conditions, the extracted information can be as detailed as an elastic layered model of the earth in the vicinity of the exploration or development target.

In the current, the synthetic geological model is used for amplitude versus offset (AVO) analysis, created by well logs and it recognized the gas bearing anomalies by the detail analyses of AVO Classes, intercept and gradient cross plots of the measured well data. The relationships of the hydrocarbon bearing zones to amplitude versus offset (AVO) attributes and elastic properties are then correlated to the seismic data to identify major reservoir seismic signatures. Class 4 AVO anomaly is interpreted from the well log data of Panjpir 01 at different incident angles. Also intercept, gradient, and cross-plot attributes had been calculated and has shown that the reflection coefficient value become strongly negative with increasing of offset. Such determinations concluded that the sands packages of Lumshiwal Formation provides Class 4 anomaly which is favorable for gas production. In light of the above interpretation, the Lumshiwal Formation falls in the category of good gas-producing reservoir.

4. Conclusions

The following conclusions are drawn from this study;

1. The time and depth migrated seismic data exhibited little variation because of non-dipping to gently dipping horizons.
2. Offset synthetic seismogram and reflection curves reveal that with the increase in offset angles the amplitude becomes less negative which indicated that the Lumshiwal Formation of Cretaceous age contains class 4 Anomaly.
3. Intercept-Gradients cross-plot shows that the values of class 4 anomaly lie in 4rth quadrant which indicated gas zone.
4. Mainly four horizons are interpreted as Sakesar, Ranikot, Lumshiwal and Samana Suk on reference seismic line and two-

way time (TWT) values of these horizons are 1080 ms, 1115 ms, 1220 ms, and 1275 ms respectively at the eastern side while gently dipping towards the west. it is interpreted that the sands package of Lumshiwal Formation has a gas-producing capability.

Acknowledgment

The authors strongly acknowledged to Directorate General of Petroleum Concession (DGPC), Islamabad to allow us data for the research purpose. The authors thank to the reviewer, who's suggestions enhance the beauty of this manuscript for the readers.

Author's contribution

Mubarak Ali, Jabir Nazir, Qazi Adnan Ahmad, and Erum Sana proposed the main concept and involved in seismic data interpretation, software and technical support (successful completion of AVO module). Abdul Basit, Abuzar Ghaffari and Beenish Ali initiated geological field and provided geological and stratigraphic details. Nazir ur Rehman, Rafique Ahmad and Salik Javed assisted in improving the overall quality of the research paper in writing, reviewing and formatting stage of the article.

References

Aadil, N., Sohail, G. M., 2011. Stratigraphic Correlation and Isopach Maps of Punjab Plateform in Middle Indus Basin, Pakistan. The 2nd South Asain Geoscience Conference and Exhibition, 1-6.

Bakhtiari, S. R., Farahbakhsh, E., Moghadam, R. H., 2014. Application of AVO Attributes and Fluid Replacement in Determining AVO Anomaly; Case Study of Aboozar Oil Field, Iran. Journal of Tethys, 2 (3), 242–253.

Belyadi, H., Fathi, E., Belyadi, F., 2019. Hydraulic fracturing in unconventional reservoirs: theories, operations, and economic analysis. Gulf Professional Publishing.

Castagna, J.P., Swan, H.W., 1997. Principles of AVO cross-plotting. The Leading Edge, 16, 337-342.

Foster, D.J., Keys, R.G., 1999. Interpreting AVO responses. 69th Ann. Internat. Mtg., Soc. Expl. Geophys., Expanded Abstracts, 748-751.

Kadri, I. B. 1995. Petroleum Geology of Pakistan.

Ross, C. P., Kinmann, D. L. 1995. Non-bright spot AVO; two examples. Journal of Geophysics, 60, 1398–1408.

Rutherford, S.R., Williams, R.H., 1989. Amplitude-versus-offset variations in gas sands. Geophysics, 54, 680-688.

Rutherford, S.R., Williams, R.H., 2016. AVO Analysis of Detecting Submarine Gas Hydrate in Lower Fangliao Basin, SW Taiwan.

Sohail, G. M., Aadil, N. 2014. 3D Geological Modeling of Punjab Platform, Middle Indus Basin Pakistan through Integration of Wireline Logs and Seismic Data. Geological Society of India, 211-217.

Verm, R. W., Hilterman, F. J. 1995. Lithologic color-coded sections by AVO crossplots. 64th Society of Exploration Geophysicists Meeting.